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Attempt to Evaluate the Errors of Satellite VTPR Temperature Data by a Climatological Method

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I. Introduction

Because data derived from satellite radiance measurements are being used increasingly in the analysis/forecast cycle, it is important that the accuracy of satellite-derived data be determined. Such determinations have been made by Johnson (1973, 1974) who compared satellite VTPR temperature soundings with rawinsonde profiles located within 1° latitude of each other and no more than 3 hours apart in time. These comparisons show root-mean-square differences between satellite and rawinsonde temperatures of $1.5^{\circ}C$ to $4^{\circ}C$, depending upon elevation and latitude, with an average value of about $2.0^{\circ}C$ at 500 mb. Similar comparisons between "co-located" satellite and rawinsonde soundings have been made by Jastrow and Halem (1973). The non-simultaneity in space and time of these paired observations has led to the criticism that the differences so determined are greater than the true differences that would be found between simultaneous and co-located satellite and rawinsonde observations.

The climatological statistics approach discussed in this paper was developed by M. Alaka, R. Elvander, and F. Lewis in conjunction with the authors in an attempt to circumvent the problem associated with interpreting the results of Johnson and Jastrow and Halem; however, this climatological method was found to have an even more serious drawback of its own.

II. The Method

The climatological method is based upon the following theoretical concept. If σ^2 is the "true" variance of a meteorological parameter (temperature, height, etc.) and ${\sigma_x}^2$ is the computed variance of the same parameter as determined from observations of type x, then

$$ {\sigma_x}^2 = \sigma^2 + {\varepsilon_x}^2 + 2\rho_x \sigma \varepsilon_x \tag{1} $$

where ε_x is the standard deviation of the error of the x-type observation and ρ_x is the correlation coefficient between the error and the true value of the parameter being measured.

If one assumes that $\rho_x = 0$ and then applies (1) to rawinsonde and satellite data, respectively, the results are

$$ {\sigma_r}^2 = \sigma^2 + {\varepsilon_r}^2 \tag{2a} $$

$$ {\sigma_s}^2 = \sigma^2 + {\varepsilon_s}^2 \tag{2b} $$

where the true variance σ^2 is considered to be identical in the expressions for both types of observation. This will be so provided the rawinsonde and satellite observations are taken over the same area and in the same time interval. Eliminating σ^2 between (2a) and (2b) and solving for ${\varepsilon_s}^2$ leads to

$$ {\varepsilon_s}^2 = {\varepsilon_r}^2 + ({\sigma_s}^2 - {\sigma_r}^2) \tag{3} $$

According to this expression, the mean-square satellite error can be determined if the mean-square rawinsonde error is known and if the observational variances σ_s^2 and σ_r^2 can be computed from climatological data.

In order to evaluate the observational variances, an area in the North Atlantic containing five weather ships was selected (Figure 1) The weather ships within this area are Ships A and I, manned by the United Kingdom, Ships B and C, manned by the United States, and Ship J, jointly manned by the United Kingdom and the Netherlands. Each of these ships is scheduled to take rawinsonde observations twice a day.

For the 3-month period June through August 1973, the operational data files of rawinsonde and satellite VTPR observations were used to compute both the rawinsonde and satellite observational variances of 500-mb temperature and geopotential height at the locations of the weather ships. For the rawinsondes, the variance computations were done in a straightforward manner. An indirect method had to be used to compute the variances associated with the satellite reports. First, the area was divided into 33 rectangular sub-areas of 3.5° latitude by 5° longitude (Figure 1). Within each of these areas, the mean values of 500-mb temperature and height were computed and plotted at the center of each rectangle. Independent hand analyses of these temperature and height fields were then performed by two analysts. The analyses were averaged graphically, and the resulting values were used to define the "mean" 500-mb temperature and height fields for the satellite data.

Next, a rectangular box of 4° latitude by 12° longitude, centered on the location of a weather ship, was delineated about each of the five ships (Figure 1). The difference between the satellite observation and the analyzed mean value at the location of the satellite report was computed for each satellite observation within the rectangular box. These differences were squared, summed, and divided by the number of observations used in order to obtain a representative satellite observational variance in the neighborhood of each ship.

If we assume that the true σ in each box is equivalent to the value of σ determined for the rawinsonde observation at the center of the area, then the rawinsonde observational variance along with an independent estimate of the mean-square rawinsonde error permit an estimate of the mean-square satellite error (equation 3). The basic assumption is that the horizontal gradient of the time variance of temperature or height is small compared to the temperature or height gradients that may exist on individual days. For this reason, the lack of exact correspondence in location between VTPR and rawinsonde observations should be much less of a problem than in the Johnson approach.

III. Results

A computer program was written by F. Lewis to extract the 3 months of rawinsonde and satellite VTPR data for the North Atlantic area from archive tapes; a separate program was written by K. Bergman to compute the observational variances σ_r^2 and σ_s^2 of equation (3). The results for 500-mb temperatures are shown in Table 1 and for 500-mb heights in

Table 2. A value of .84°C is given as the root-mean-square temperature error of the U. S. rawinsonde instrument (Alaka and Elvander, 1972) and of approximately 1.0°C for the Kew Mark II instrument used by both the United Kingdom and the Netherlands (more precise value unobtainable). These values are entered for ε_r in Table 1. Corresponding height errors, as determined from the 1000-500 mb thickness relationship, are entered in Table 2.

Table 1 shows that, with the exception of Ship J, the values of σ_s^2 are smaller than σ_r^2, contrary to original expectations. In fact, the data for Ships B, C, and I give physically impossible negative values for ε_s^2. Table 2 shows that similar results obtain for the 500-mb height errors ε_s^2, with the exception of Ship A.

IV. Conclusion

The most logical reason for the failure of this approach is that ρ_x in equation (1) is not zero or small for the satellite VTPR observations.

If, instead of equation (2b) for the satellite observational variances, we write

$$\sigma_s^2 = \sigma^2 + \varepsilon_s^2 + 2\rho_s\sigma\varepsilon_s \,, \tag{4}$$

then solution of this equation together with equation (2a) for σ_r^2 results in

$$\rho_s = \frac{(\sigma_s^2 - \sigma_r^2) + (\varepsilon_r^2 - \varepsilon_s^2)}{2\varepsilon_s\ (\sigma_r^2 - \varepsilon_r^2)^{\frac{1}{2}}} \tag{5}$$

It is obvious that a unique solution for ε_s is no longer possible unless the value of ρ_s is known. However, equation (5) can be used to estimate ρ_s for values of ε_s given by K. Johnson or other independent source.

In order to estimate ρ_s, equation (5) was solved for the computed values of the observational variances $\sigma_s{}^2$ and $\sigma_r{}^2$ assuming 2°C for the standard deviation of the satellite error. These results are shown in Table 3. The mean value of ρ_s for all five ships is -.361. Similar computations for 500-mb heights are given in Table 4, where the mean value of ρ_s for the five ships is -.359. (In Table 4, Ship A diverges from the overall pattern in giving a slightly positive value of ρ_s.)

The negative values of ρ_s indicated above imply that VTPR observations tend to be conservative in the sense that they underestimate the extremes of temperature or height. This may be related to the relatively low resolution of the VTPR reports. Or it may be associated with the use of forecast values as a "first guess" for the temperature retrieval. In either case, our conclusion is that there is a sizeable negative correlation between VTPR errors and temperatures for given pressure layers or levels and that without knowing this correlation, the climatological approach described above cannot be used to estimate the errors in VTPR reports.

The scatter in the values of ρ_s obtained indicate that either a sufficiently long climatological period was not used in the computations, or the mean field analyses constructed for computation of the satellite observational variances were not constructed with sufficient accuracy, or both. The departure of Ship A from the trend indicated by the other ships may be due in part to the fact that only 53 rawinsonde observations were made at this ship during the 3-month period. This is a relatively small sample compared to those at the other ships.

REFERENCES

1. Alaka, M. A., and R. C. Elvander, 1972: Optimum interpolation from observations of mixed quality. Mon. Wea. Rev., 100, 612-624.

2. Jastrow, R., and M. Halem, 1973: Accuracy and coverage of temperature data derived from the IR radiometer on the NOAA-2 satellite. J. Atmos. Sci., 30, 958-964.

3. Johnson, K., 1973, 1974: Tabulations of differences between VTPR and rawinsonde temperature data. NMC Newsletter, June 1973 and succeeding issues through Jan. 1974.

TABLE 1. 500-MB TEMPERATURES

SHIP	σ_r (°C)	σ_r^2 (°C²)	NO. OF OBS.	σ_s (°C)	σ_s^2 (°C²)	NO. OF OBS.	(EST.) ε_r (°C)	ε_r^2 (°C²)	ε_s (°C)	ε_s (°C²)
A	4.041	16.330	53	4.007	16.056	112	1.0	1.0	.852	.726
B	4.317	18.636	108	3.464	11.999	93	.84	.706	---	-5.931
C	3.821	14.600	90	3.440	11.834	82	.84	.706	---	-2.060
I	4.454	19.838	119	3.915	15.327	104	1.0	1.0	---	-3.511
J	3.715	13.801	109	3.787	14.341	114	1.0	1.0	1.241	1.540

TABLE 2. 500-MB HEIGHTS

SHIP	σ_r (m)	σ_r^2 (m²)	NO. OF OBS.	σ_s (m)	σ_s^2 (m²)	NO. OF OBS.	(EST.) ε_r (m)	ε_r^2 (m²)	ε_s (m)	ε_s^2 (m²)
A	86.93	7557	53	95.60	9139	112	20.0	400	44.52	1982
B	104.12	10,841	110	87.53	7662	93	17.0	289	-----	-2890
C	110.65	12,243	89	93.22	8690	82	17.0	289	-----	-3264
I	118.08	13,943	119	104.44	10,908	104	20.0	400	-----	-2635
J	96.03	9222	109	90.53	8196	114	20.0	400	-----	-626

TABLE 3. ρ_s FOR 500-MB TEMPERATURES

SHIP	σ_r (°C)	NO. OF OBS.	σ_s (°C)	NO. OF OBS.	(EST.) ε_r (°C)	(EST.) ε_s (°C)	ρ_s
A	4.041	53	4.007	112	1.0	2.0	-.209
B	4.317	108	3.464	93	.84	2.0	-.586
C	3.821	90	3.440	82	.84	2.0	-.406
I	4.454	119	3.915	104	1.0	2.0	-.433
J	3.715	109	3.787	114	1.0	2.0	-.172

TABLE 4. ρ_s FOR 500-MB HEIGHTS

SHIP	σ_r (m)	NO. OF OBS.	σ_s (°C)	NO. OF OBS.	ε_r (°C)	ε_s (°C)	ρ_s
A	86.93	53	95.60	112	20.0	40.0	+.056
B	104.12	110	87.53	93	17.0	40.0	-.546
C	110.65	89	93.22	82	17.0	40.0	-.556
I	118.08	119	104.44	104	20.0	40.0	-.455
J	96.03	109	90.53	114	20.0	40.0	-.296

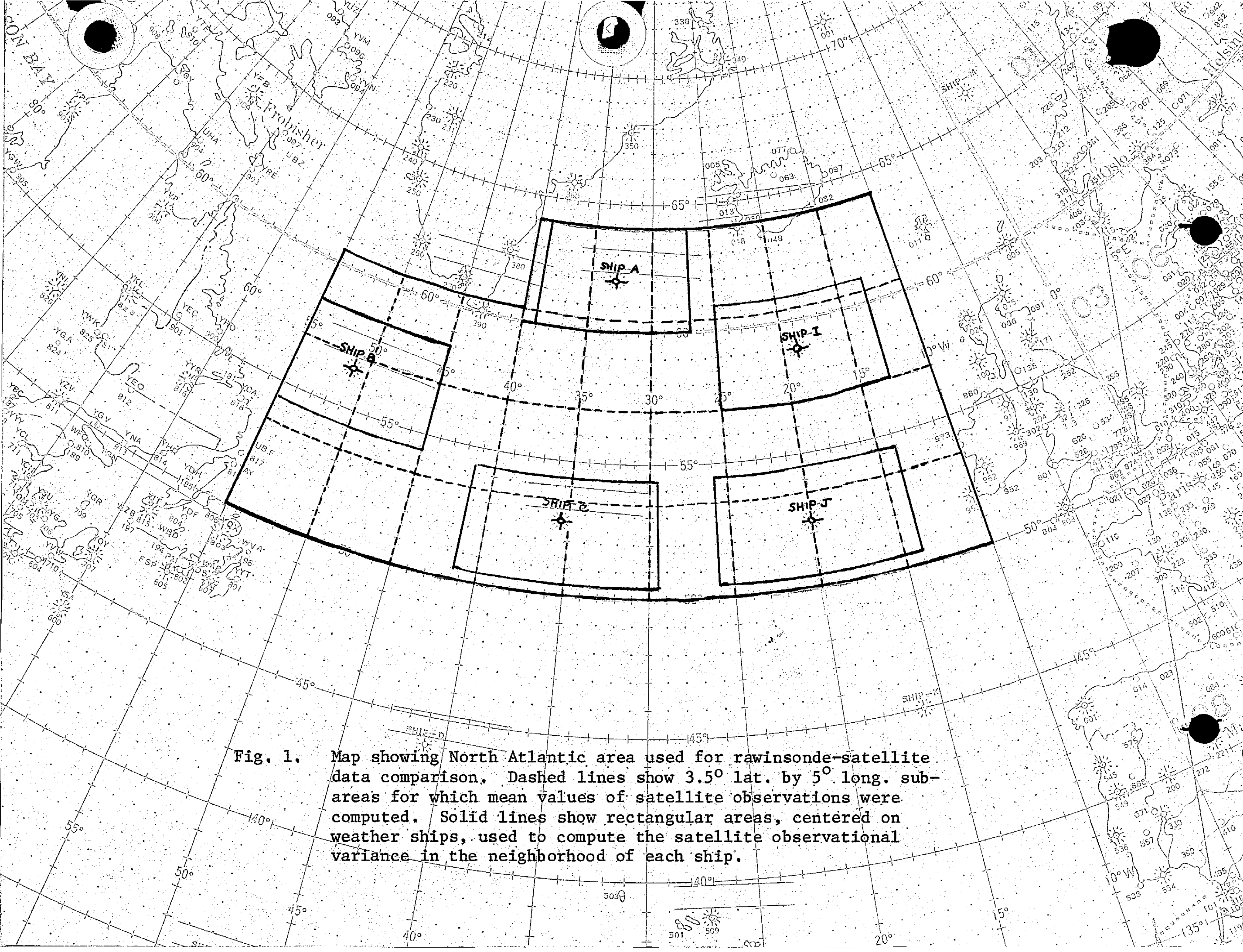

Fig. 1. Map showing North Atlantic area used for rawinsonde-satellite data comparison. Dashed lines show 3.5° lat. by 5° long. sub-areas for which mean values of satellite observations were computed. Solid lines show rectangular areas, centered on weather ships, used to compute the satellite observational variance in the neighborhood of each ship.